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ABSTRACT

The way cognitive, event-related brain potentials (ERPs) can aid in further understanding of memory span change in children is discussed. ERPs are time-dependent changes in electrical activity of the brain (as recorded by scalp electrodes) following the presentation of a physical stimulus through auditory, visual, or somatosensory modalities. The cognitive components which are elicited by the processing demands of the task are relatively independent of the physical character of the stimuli. One of the most studied of the cognitive components is the P300 or P3, elicited by task relevant events. Research findings indicate that people who quickly generate the P3 tend to have a larger memory span at any age, that minimal latency of the P3 is associated with the onset of puberty, and that P3 latency, an age sensitive variable, can serve as an estimate of the time required for stimuli to be identified and classified with respect to task demands. Research further suggests that stimulus identification processes are less efficient among children. In addition, speed of item identification as measured by the P3 has been found to determine the size of memory span, to the extent that early processing is involved. It can be concluded that a significant proportion of the variance of memory span development is tied to the speed of stimulus identification processes and that ERPs provide an important additional metric for analyzing the ontogeny of working memory capacity. (RH)

P300 LATENCY AND THE DEVELOPMENT OF MEMORY SPAN

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The purpose of this talk is to illustrate how cognitive event-related brain potentials or ERPs can aid our understanding of memory span change in children by helping to specify the nature of processing speed development. This technique will show that the processes of item identification contribute to the development of span. A brief review of the literature will motivate this claim.

Span has been studied for some time. The exercise of strategic skills such as rehearsal and the recoding employed in chunking parallel the increase in memory span observed during childhood. Recently, speed of processing has been proposed as the final factor to complete this explaination: the faster children can perform a set of critical behaviors, the larger will be the size of their memory span.

The work of the researches at this symposium leaves no doubt that temporal processes do contribute to span development. The debate seems to be over just which cognitive processes are involved.

Chi (1977) specifies the early processes of encoding and name retrieval as the critical loci of speed. Hulme et al.(1984) point to increasing speed in the motor responses required to articulate stimulus words. Case et al. (1982) claim that the attentional demands of processing items costs small children the storage space that older children and adults enjoy.

These divergent interpretations raise the question as to whether behavioral measures alone are sufficient to decide among these alternatives. Complementing behavioral measures of processing speed with the findings of an additional metric that responds selectively to stages of information processing may help resolve these sorts of questions. Recent ERP research from my laboratory suggests that speed of identifying stimuli contributes to the growth of children's memory span. It further appears that this increase in speed does not reflect the use of strategies or the speed of articulation and must occur in the early stages of information processing involved in a memory task.

This work began with Arnold Starr and John Polich at the Department of Neurology at UC Irvine when they were studying the memory deficits found in dementing illness with ERPs. Since both demented individuals and healthy children show rapid changes in memory (albeit in opposite directions) over a short period of time, normal developoment looked like an ideal model to test the sensitivity of the ERP measure to memory changes.

Event-related potentials are time-dependent changes in electrical activity of the brain as recorded by scalp electrodes following the presentation of a physical stimulus through auditory, visual or somatosensory modalities. It is possible to extract from the EEG the electrical activity that is uniquely associated with the occurrence of this particular event, and to discriminate whether these events reflect sensory changes or are 'cognitive'in nature. Because the magnitude of the EEG is much greater than the response from a stimulus, signal averaging is employed to extract this neural information (Figure 1).

Insert Figure 1 about here

The record appears as a series of voltage oscillations of various amplitudes and latencies. This whole record can be analyzed into functional <u>components</u> or smaller segments of the overall record that are singled out on the basis of variations in latency, amplitude or scalp topography. In this example they are labelled N1 and P2.

Figure 2 represents the main components associated with typical sensory and cognitive functions. Sensory potentials are said to be

Insert Figure 2 about here

evoked by the stimulus and are sometimes called the exogenous components. These evoked potentials are responses to stimuli which reflect the sensory modality, physical attributes of the stimulus, and the neurological integrity of the sensory pathways. They are unaffected by factors such as attention or task instruction. The measurment of these components are regularly done in clinical settings to study sensory functions

The cognitive components, by contrast, are <u>elicited</u> by the processing demands of the task and are relatively independent of the physical character of the stimuli. These begin to occur about 100 msec after the stimulus presentation and they tend to be relatively large in amplitude.

One of the most studied of the cognitive components is the P300 or P3. This is a large (10-20 uV) component with a modal latency of 300 msec in young adults. It is elicited by task relevant events, often with what has been termed an auditory "odd-ball" task. In this task (Figure 3) the subject is presented with two tones, one at 1000 Hz and the other at 2000 Hz, which occur randomly 80% and 20% of the trials, respectively. The subject is instructed to attend to and keep a mental count of the occurrences of the "odd ball" or rare tone (Note 1). In Figure 3 the ERP record elicited by the frequent tone is compared with the record elicited by the rare tone for four subjects. The recording is repeated for each subject to ensure a reliable assessment. A large positive wave occurs on the trace of the rare tone. On many records, as is evident here, a 'P3a' and a 'P3b' sub-component can be observed. These factors appear to involve different factors and can be manipulated experimentally. The distinction is not essential for the remainder of this argument (Note 2).

Insert Figure 3 about here

The amplitude of the P3 is inversely proportional to the subjects expectancy of the target: when the stimuli are relevant to the task, the amplitude of the P3 increases monotonically as the probability of occurrence of the target declines (Duncan-Johnson & Donchin, 1977). This is shown in Figure 4. The amplitude of the P3 is thought to reflect the "suprise value" of the stimulus, or the amount of "context updating"

Insert Figure 4 about here

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required as the new stimulus event is identified and compared with the memorial record of previous events. Infrequently occurring events elicit a larger amplitude P3 than do more frequent events because they require a greater change in the memorial representation of the context (Donchin, 1981).

The latency of the P3 can therefore be used to measure the time required for this updating to be completed. P3 latency can serve as an estimate of the time required for eliciting stimuli to be identified and classified with respect to the task demands at hand (Donchin, 1979). Since P3 latency is virtually unaffected by factors that affect the selection and execution of a response, the selective sensitivity of P3 latency underlines its potential as a an additional metric of information processing. Factors that affect P3 latency include relative difficulty in identifying stimuli, cognitive impairment due to trauma or disease, as well as the normal processes of maturation and aging.

For example, stimuli that are harder to distinguish exhibit delays in the latency of P300. Subjects in Figure 5 are distinguishing the target

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Insert Figure 5 about here

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tone from the background or standard tone in a clear environment and in one containing a 60 Hz white noise hiss, when the target tone is easier (4000 Hz or 2000 Hz) or harder (1500 Hz) to distinguish from the 1000 Hz standard (Polich, Howard, and Starr, 1985). Both difficulty in discriminating the target and the presence of noise affect the latency of the P300 subcomponents in a strictly additive manner.

McCarthy and Donchin (1981) in a visual choice reaction time study (Figure 6) instructed subjects to make either compatable responses

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Insert Figure 6 about here

(pressing a button in the left hand when shown the word 'left') or an incompatable response (pressing the button held in the left hand when shown the word 'right'). Figure 7 shows that P3 latency and reaction

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Insert Figure 7 about here

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time were recorded as the stimulus word was presented in noise and no-noise conditions. Difficulty in identifying items and in selecting a response both slow reaction time, while only difficulty of identifying the target (noise) slows the latency of P3. The P3 reflects identification and categorization processes that are independent of response selection.

P3 latency is also affected by the presence of cognitive impairment. Figure 8 compares P3 latency recorded from healthy elderly subjects with the P3 recorded from similarly aged individuals suffering from various dementing illnesses such as Alzheimer's disease (Goodin et al., 1978). P3 latency alone of the late components was delayed over two standard

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Insert Figure 8 about here

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deviations in the demented subjects, all of whom suffered from marked memory impairment. In a subsequent study, P3 latency was shown to reflect the <u>degree</u> of cognitive impairment (Polich et al., Note 3; Figure 9).

Insert Figure 9 about here

Age of the subject also affects the latency of the P3. Figure 10 illustrates a sample of 96 healthy subjects ranging in age from 5 to 86 years who were studied at UCI using the replicated trial procedure. The latency of the P3 is quite long in small children, rapidly speeding up to minimal latency in mid-to-late teens, and gradually slowing down with increasing age (Polich, Howard, Starr, 1985). This course parallels the change in other age sensitive variables. For example, during this same period of rapid decline in the latency of the P3 during childhood, the memory span is making a dramatic spurt.

Insert Figure 10 about here

This potential link of P3 latency and cognitive capacity was explored by comparing P3 latency with the combined forward and reverse digit spans of the individuals in the aging study (Figure 11). A strong relationship between digit span and latency of the P3 was found, a correspondence not shown by other late components. This relationship even improved when the effects of age were partialled out statistically ($r = -.52$ for P3a, $r = -.40$ for P3b): if people are fast in generating the P3, they tend to have a larger memory span at any age (Polich, Howard, and Starr, 1983).

Insert Figure 11 about here

Comparing a sample of children with a sample of young adults on this same pair of tasks, the effect became even more striking (Figure 12). P3 latency accounted for a considerable amount of the variance of digit span scores in children ($r = -.59$) while exhibiting essentially no explanatory

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Insert Figure 12 about here

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power in young adults (r = -.21; Howard and Polich, 1985). Given the restricted range of adult memory scores, this latter fact is not suprising.

The correlation of P3 latency with digit span implies that delays in children's speed in performing an auditory memory task are located in processes that occur while stimuli are being identified and categorized.

I have been investigating this relationship of stimulus evaluation speed and memory span development by examining a larger sample of children with a wider spectrum of memory measures. Even small children will eagerly cooperate with the process of "making brainwaves" if made co-investigators who are given an active sense of control in the situation, such as inserting their electrode leads into the averager. Figure 13 presents repeated measures of the auditory odd-ball task for typical subjects from the five groups currently being studied. Both average latency and amplitude of the P3 are presented for each subject.

Insert Figure 13 about here

The latency of the P3 component diminishes quite rapidly to a minimum in mid-teens, replicating our earlier findings. The proximity of the region of minimal latency to the onset of puberty suggests a maturational process is affecting P3 latency. Figure 14 shows that the relationship found earlier between P3a and P3b latency and digit span in children is also replicated in this larger sample.

Insert Figure 14 about here

Figure 15 illustrates the variability found within each group. The records of four subjects within each age group are printed over the same

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Insert Figure 15 about here

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coordinates. For all subjects the P3 is apparent. The younger subjects show both greater variability in their record and greater similarity between the ERPs elicited by the two tones than do older subjects. It is interesting to note that though young children are accurate in discriminating between the tones, as their count of the number of occurrences of the target shows, they respond to the frequently occurring tone much as they do to the target tone: a large P3 occurs on both records, whereas only a vestigial P3 occurs on the ERP elicited by the frequent tone in adults. Seemingly children must devote resources to context updating not only on the occasion of a rare event, but to frequent and expected events as well. The process of identification seems to be less efficient for children.

How then may the relationship of memory span and stimulus identification time that occurs in children be understood? The P3 is triggered by the completion of the process of stimulus identification, a process which may reflect delays in either encoding stimuli or in retrieving their long-term representation. Hence, the association of fast P3 with large memory span cannot be explained by appealing to accelerated response processes, including articulation.

Secondly, since item identification time was measured with a very simple auditory discrimination task (the odd-ball), the advantages of recoding and rehearsal enjoyed by older children and adults will not serve to distinguish them from younger subjects: the task demands are the same. Thus subjects of widely different ages can be compared on a task that is seemingly strategy free. The differences children exhibit in stimulus identification time would seem to be maturational in nature, reflecting perhaps the increased mylination or dendritic differentiation of the nervous system (Klorman et al., 1978).

Finally, since the memory span task employed to compare children and adults (digit span) is sensitive to the skill in rehearsal and recoding that older children and adults enjoy, the degree of association of stimulus identification and span is probably underestimated. If this is correct, then P3 latency may serve as a relatively precise indicator of a maturational component of human memory, the effects of which are best seen when strategic skills are absent or suppressed.

These findings suggest that there is a distinct trade off between stimulus identification demands and the size of working memory because processing delays do not involve the production of a response or admit much assistance from the skills that are known to support memory span. Further support for this inference can be drawn from a study by Karis, Fabiani, and Donchin (1984), who found that P3 predicted recall for discrepant items in the middle serial positions only for those adults who employed rote rehearsal strategies in constrast to those adults who used elaborative rehearsal strategies. The interpretation outlined above would seem to apply here: speed of item identification as measured by the P3 determines the size of memory span to the extent that early processing, that which is completed within a second, is involved. This is supplemented by increasingly sophisticated mnemonic strategies and recoding that operate when items are being organized into groups or rehearsal sets -- processes that occur after a second or so has passed.

Thus, it can be concluded that a significant proportion of the variance of memory span development is tied to the speed of stimulus identification processes. This view complements the evidence of temporal involvement at other processing stages, suggesting that temporal delays may occur at several points during the complex of events that support working memory. To the extent that these are opaque to behavioral measures, ERPs provide an important additional metric to analyse the ontogeny of working memory capacity.

Notes

1. Counting is not required to elicit a P3. We employ the counting task to ensure the subject is doing what is essential to the P3: attending to the occurrence of the rare tone. With small children who have difficulty in counting the tones, we instructed them to simply "tap mommy's hand" with each occurrence of the target tone. The parent remembered and reported the number of taps. Children readily mastered this task. We compared the records of a group of older children (8 - 12 years) and young adults under both count and tap conditions and found no difference in P3 latency.

2. These components appear to reflect different factors involved in stimulus evaluation. When we report "P3" without specification, we are reporting the largest amplitude component on a given block of trials whether it is an 'a' or a 'b.' Since these factors are additive, the distinction has no direct impact on the general argument of this paper. C.f. Polich, Howard, & Starr (1983) for a fuller discussion and references.

3. Polich, J., Ehlers, C. L., Otis, S., Mandell, A. J., & Bloom, F. P300 latency reflects the degree of cognitive decline in dementing illness. Manuscript submitted for publication, 1984.

References

Case, R., Kurland, D.M., & Goldberg, J. (1982). Operational Efficiency and the growth of short-term memory span. Journal of Experimental Child Psychology, 33, 386-404.

Chi, M.T.H. (1977). Age differences in memory span. Journal of Experimental Child Psychology, 1977, 23, 266-281.

Courchesne, E. The maturation of cognitive components of the event-related brain potential. (1981). In A.W.K. Gaillard & W. Ritter (Eds.), Tutorials in ERP Research: Endogenous Components. Amsterdam: North-Holland Publishing Co.

Donchin, E. (1979). Event-related brain potentials: A tool in the study of human information processing. In H. Begleiter (Ed.), Evoked Brain Potentials and Behavior. New York: Plenum Press.

Donchin, E. (1981). Suprise!...Suprise? Psychophysiology, 18, 493-513.

Duncan-Johnson, C.C. (1981). P300 latency: A new metric of information processing. Psychophysiology, 18, 207-215.

Duncan-Johnson, C.C.,& Donchin, E. (1977). On quantifying suprise: The variation of event-related potentials with subjective probability. Psychophysiology, 14, 456-467.

Goodin, D., Squires, K., & Starr, A. (1978). Long-latency event- related components of the auditory evoked potential in dementia. Brain, 11, 635-648.

Howard, L., & Polich, J. (1985). P300 latency and memory span development. Developmental Psychology, 21, 283-289.

Hulme, C., Thomson, N., Muir, C., Lawrence, A.(1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology*, *38*, 241-253.

Karis, D., Fabiani, M., & Donchin, E.(1984). "P300" and memory: Individual differences in the von Restorff effect. *Cognitive Psychology*, *16*, 177-216.

Klorman, R., Thompson, L.W., & Ellingson, R. J. (1978). Event related brain potentials across the life span. In E. Callaway, P. Tueting, & S.H. Koslow (Eds), *Event-related brain potentials in man*. New York: Academic Press.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science*, *197*, 729-795.

McCarthy, G., & Donchin, E.(1981). A metric for thought: A comparison of P300 latency and reaction time. *Science*, *211*, 77-80.

Picton, T. W., Hillyard, S. A., Krausz, H. T., & Galambos, R.(1974) Human auditory evoked potentials, I: Evaluation of components. *Electroencephalography & Clinical Neurophysiology*, *36*, 179-190.

Picton, T. W., & Hink, R. F. Evoked potentials: How? What? And why? (1974). *American Journal of EEG Technology*, *14*, 9-44.

Picton, T. W. Stuss, D. T., Champagne, S. C., & Nelson, R. F. (1984). The effects of age on human event-related potentials. *Psychophysiology*, *21*, 312-325.

Polich, J., Howard, L., & Starr, A. (1983). P300 latency correlates with digit span. *Psychophysiology*, *20*, 665-669.

Polich, J. Howard, L., & Starr, A. Aging effects on the P300 component of the event-related potential from auditory stimuli: Peak definition, variation, and measurment. Journal of Gerontology, in press.

Polich, J.M. & Starr, A. Evoked potentials in aging.(1982). In M.L. Albert (Ed.), Clinical Neurology of Aging. New York: Oxford University.

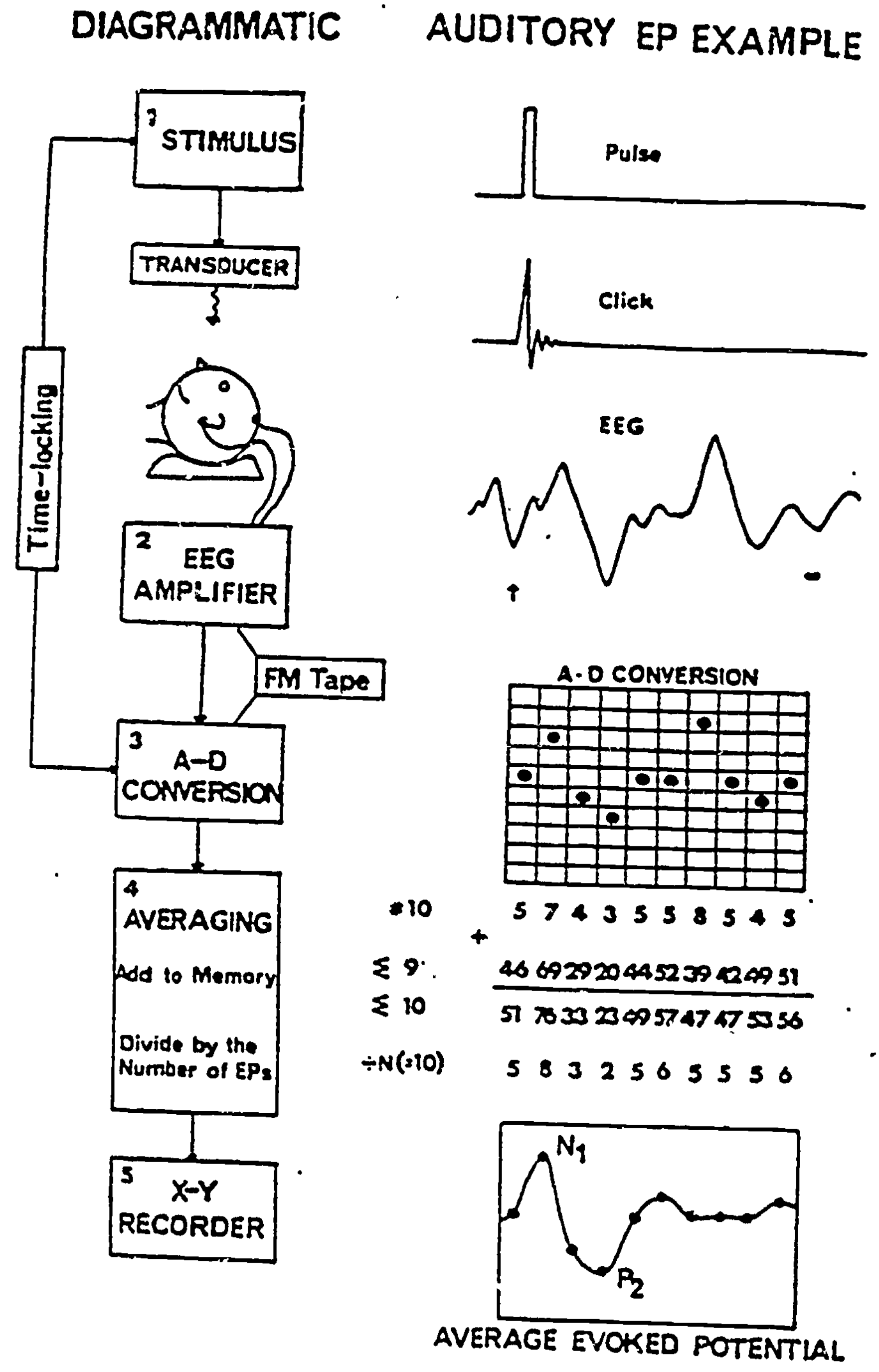
Pritchard, W. S. Psychophysiology of P300. (1981). Psychological Bulletin, 89, 506-540.

Squires, N. K., Squires, K. C., & Hillyard, S. A.(1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography & Clinical Neurophysiology, 38, 387-401.

Sutton, S., Tueting, P., Zubin, J.,& John, E.R.(1965). Evoked-potential correlates with stimulus uncertainty. Science, 150, 1187-1188.

Figure 1

EVOKED POTENTIALS: HOW? WHAT? AND WHY?



Overview of Evoked Potential Techniques

(From Picton, 1974)

Main Components of Sensory and Cognitive Potentials

SENSORY POTENTIALS				COGNITIVE POTENTIALS
Modality	0 - 10 msec	10 - 80 msec	80 msec	~ 100 - 1000 msec
AUDITORY	ABRs Waves I - VII	Middle Latency Na, Pa, Nb, Pb, Nc	Long Latency N1, P2, N2	N100 (Attention) P200 (Early Processing) N200 (Detection) P300 (Surprise,Decision) CNV (Preparation)
VISUAL	---	---	P100	
SOMATO-SENSORY	N7 N10 P11 N13	N18 P30 P20 N40 N20/N22 N50 P60	---	

Figure 2

Figure 3

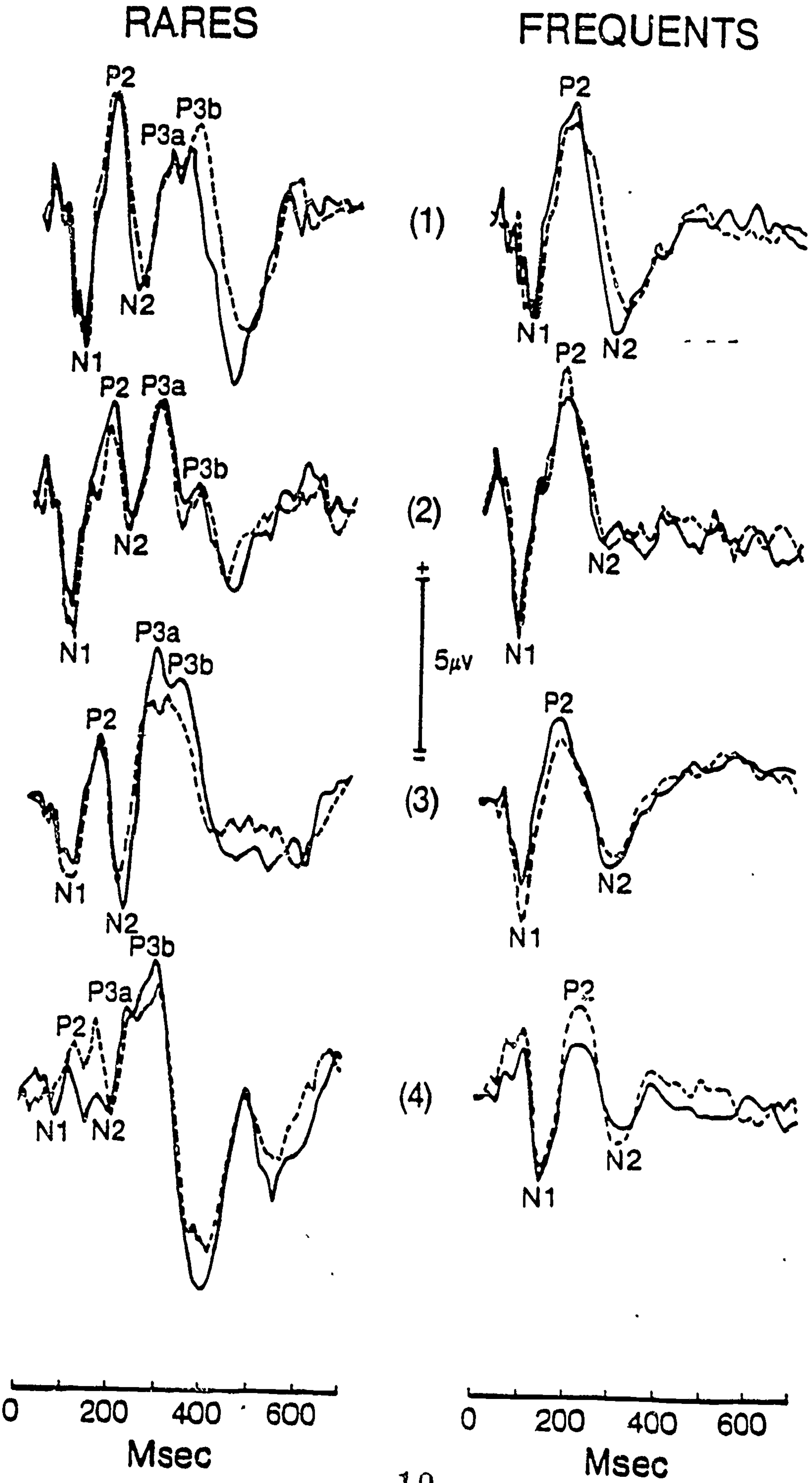
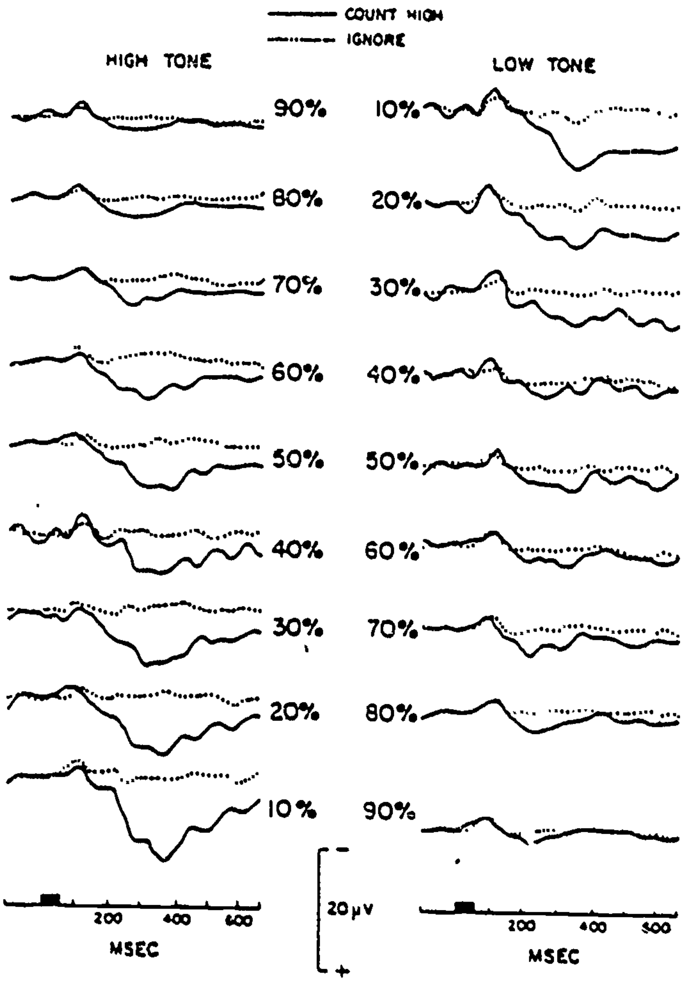

RARES
FREQUENTS
P2
P3b
P3a
N2
N1
(1)
P2
N1
N2
P2
P3a
P3b
N2
N1
(2)
P2
N2
N1
+
5µv
P3a
P3b
P2
N1
N2
(3)
P2
N2
N1
P3b
P3a
P2
N1
N2
(4)
P2
N2
N1
0
200
400
600
Msec
0
200
400
600
Msec

Figure 4



(From Duncan-Johnson, 1977)

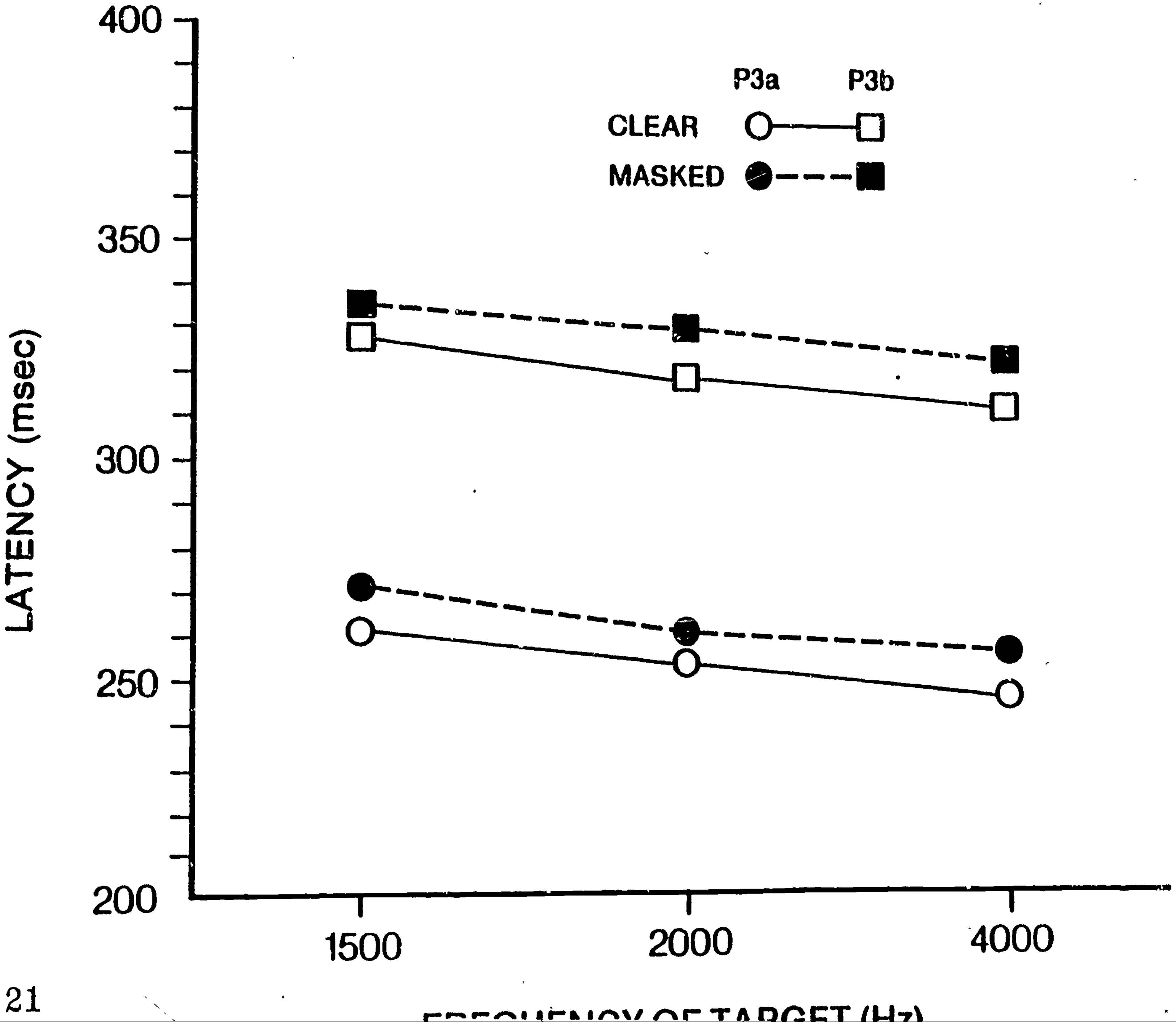
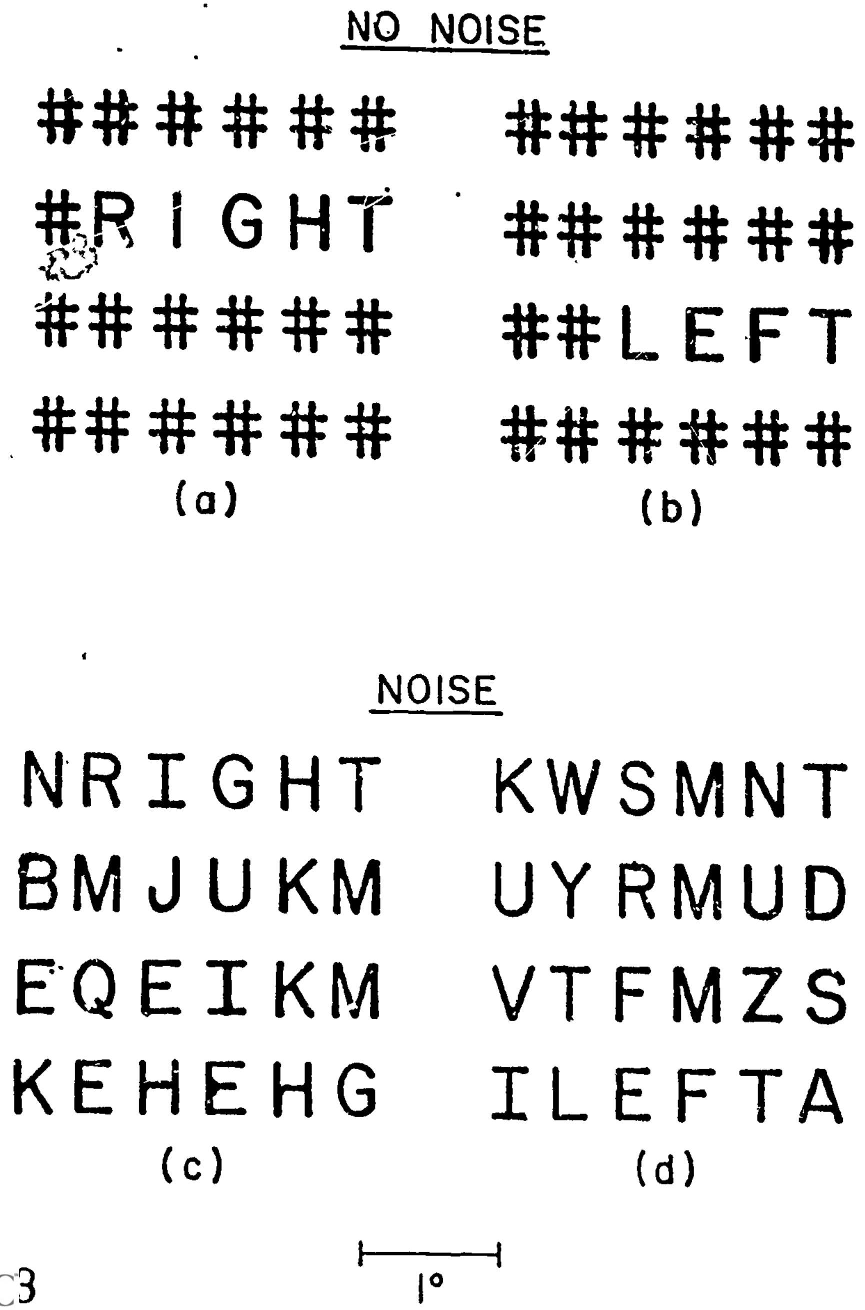

400
350
300
250
200
LATENCY (msec)
P3a
P3b
CLEAR
MASKED
1500
2000
4000
FREQUENCY OF TARGET (Hz)

Figure 5

Figure 6



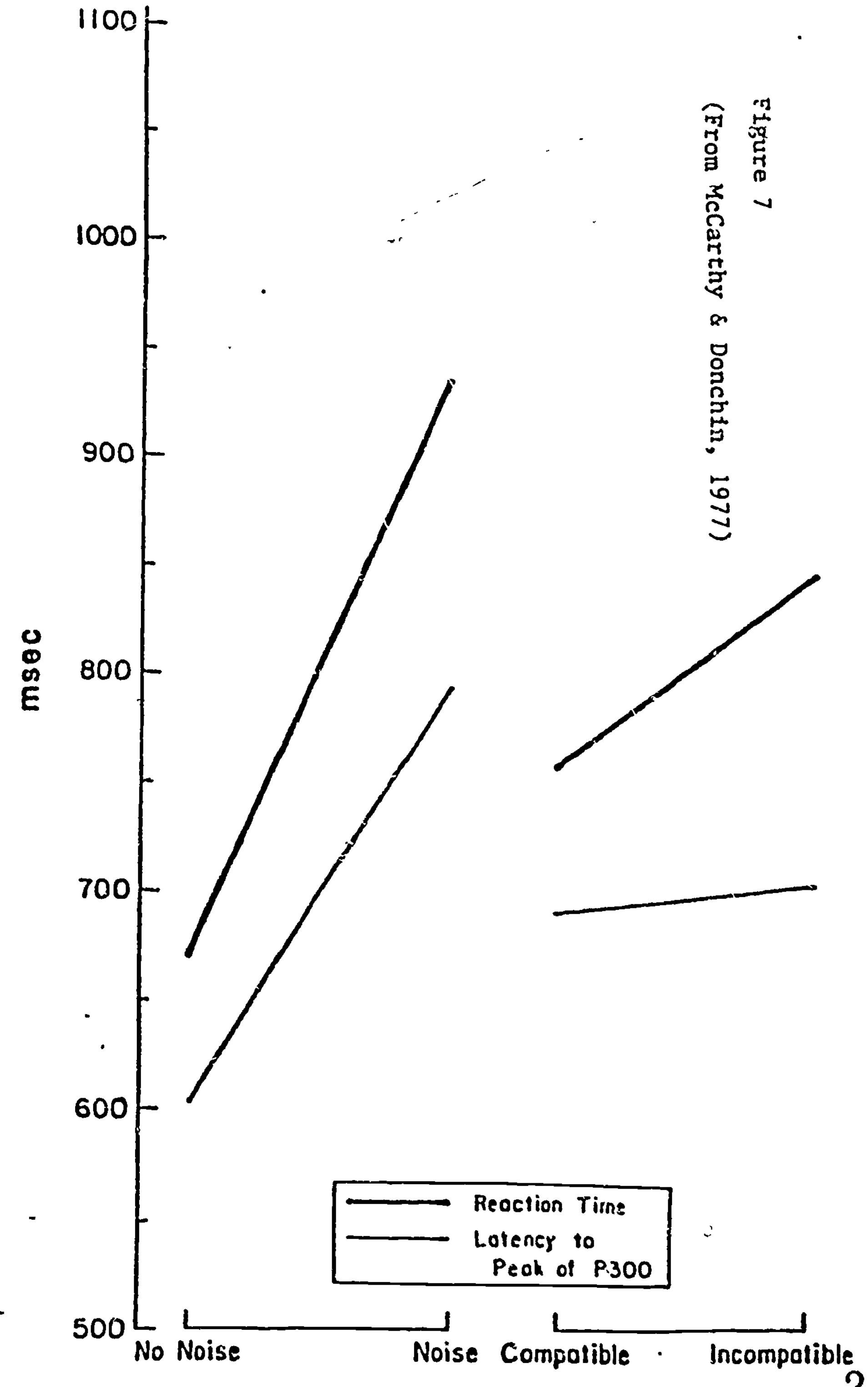
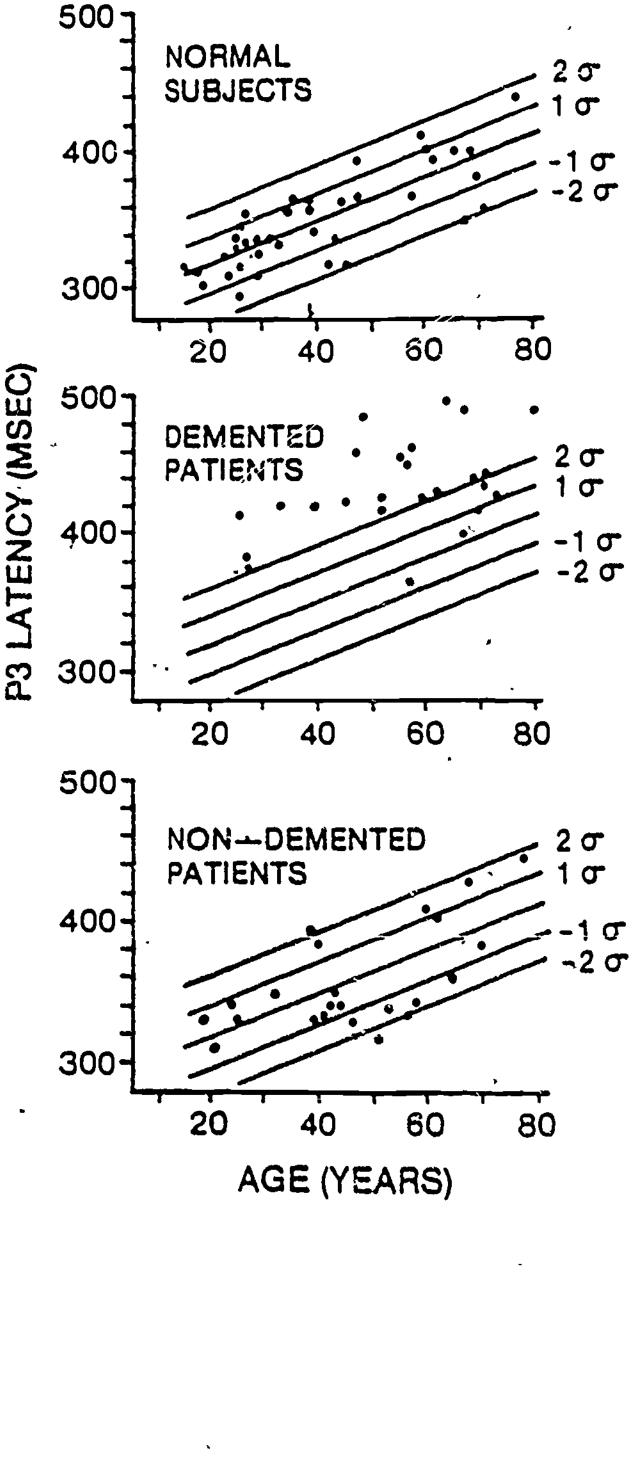


Figure 7
(From McCarthy & Donchin, 1977)

(From Goodin et al., 1978) Figure 8



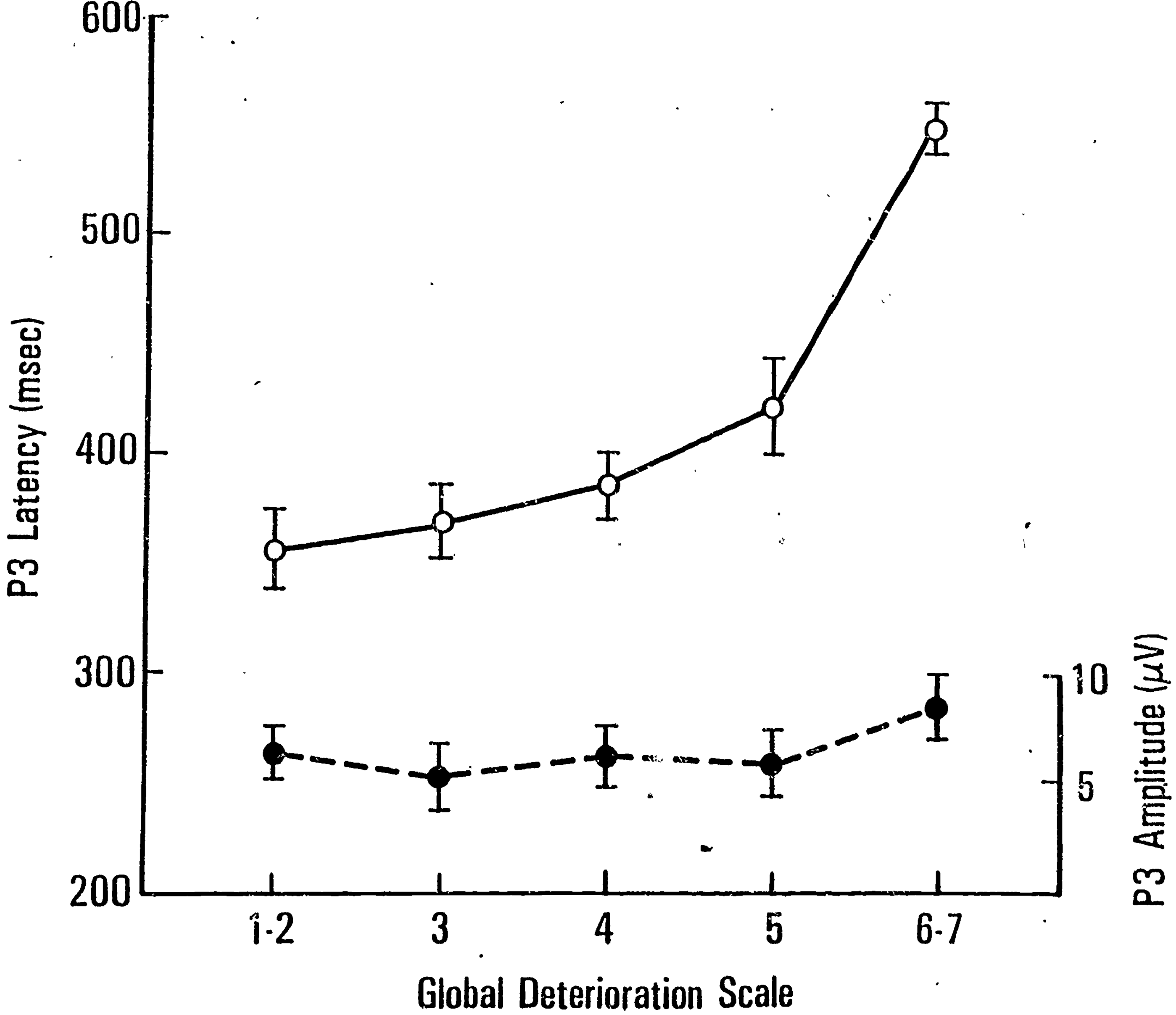

600
500
400
300
200
P3 Latency (msec)
10
5
P3 Amplitude (μV)
1-2
3
4
5
6-7
Global Deterioration Scale

Figure 9

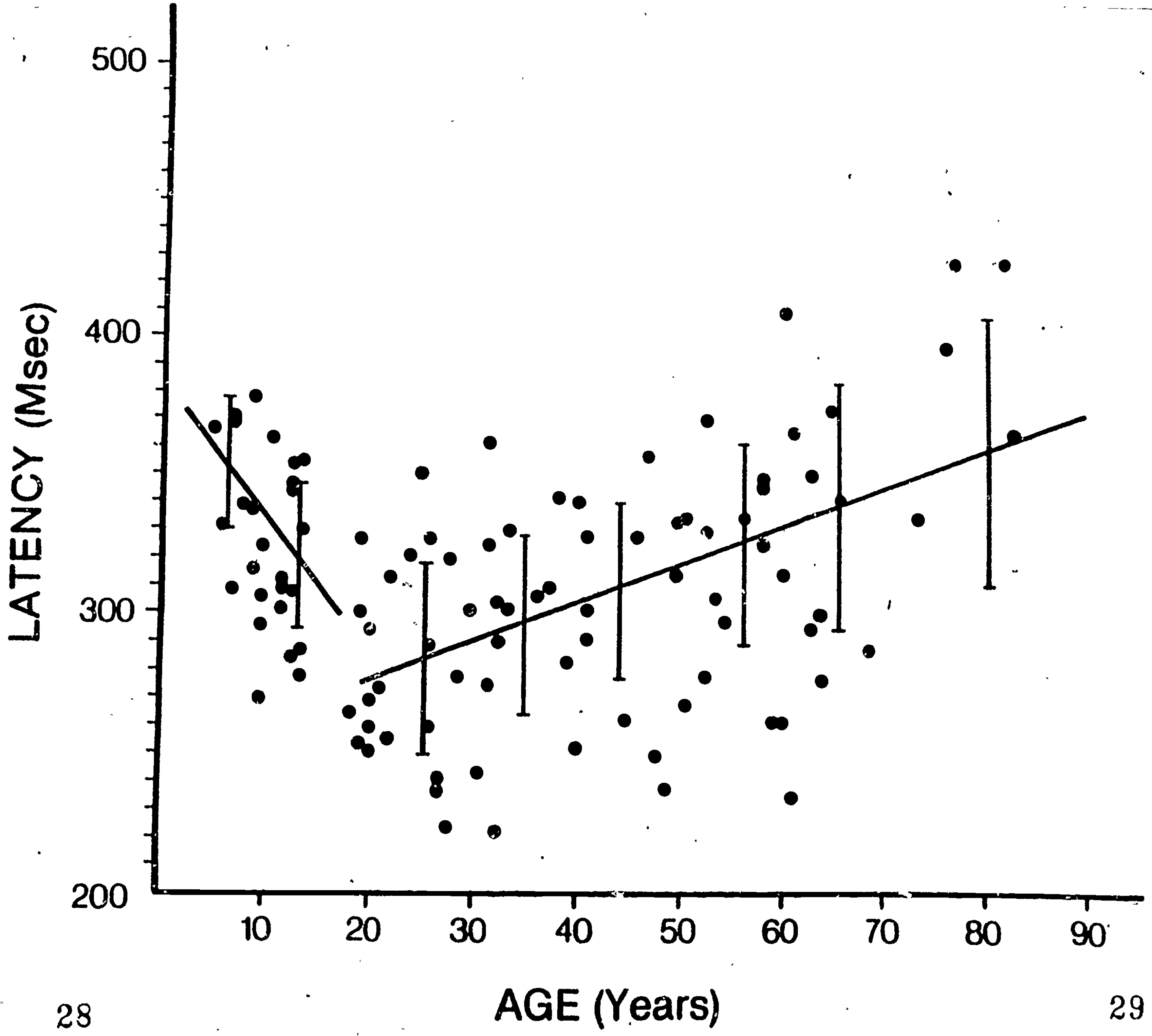


Figure 10

Figure 11

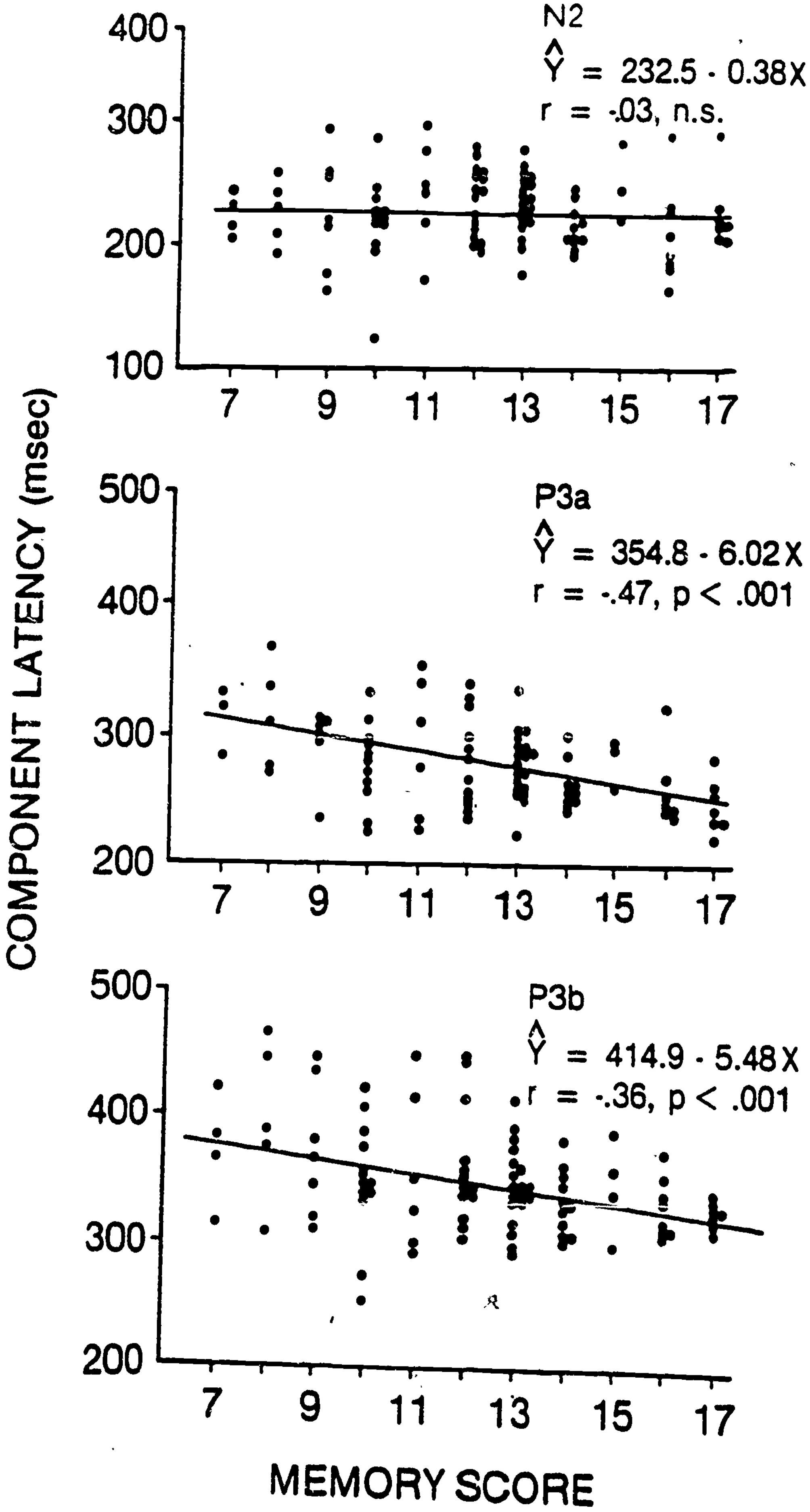

N2
$\hat{Y} = 232.5 - 0.38X$
$r = -.03$, n.s.
400
300
200
100
P3a
$\hat{Y} = 354.8 - 6.02X$
$r = -.47, p < .001$
500
400
300
200
P3b
$\hat{Y} = 414.9 - 5.48X$
$r = -.36, p < .001$
500
400
300
200
7
9
11
13
15
17
COMPONENT LATENCY (msec)
MEMORY SCORE

Figure 12

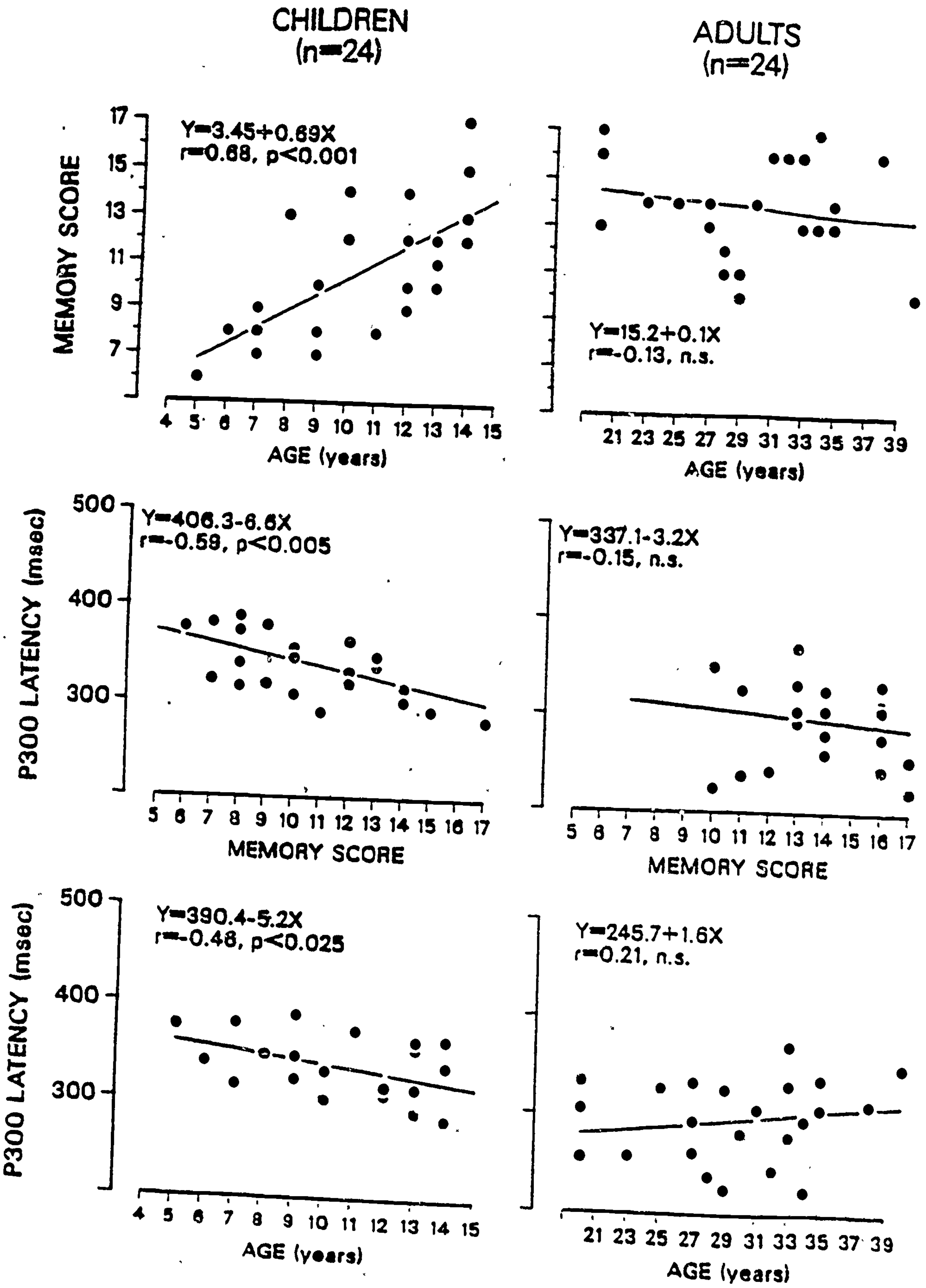
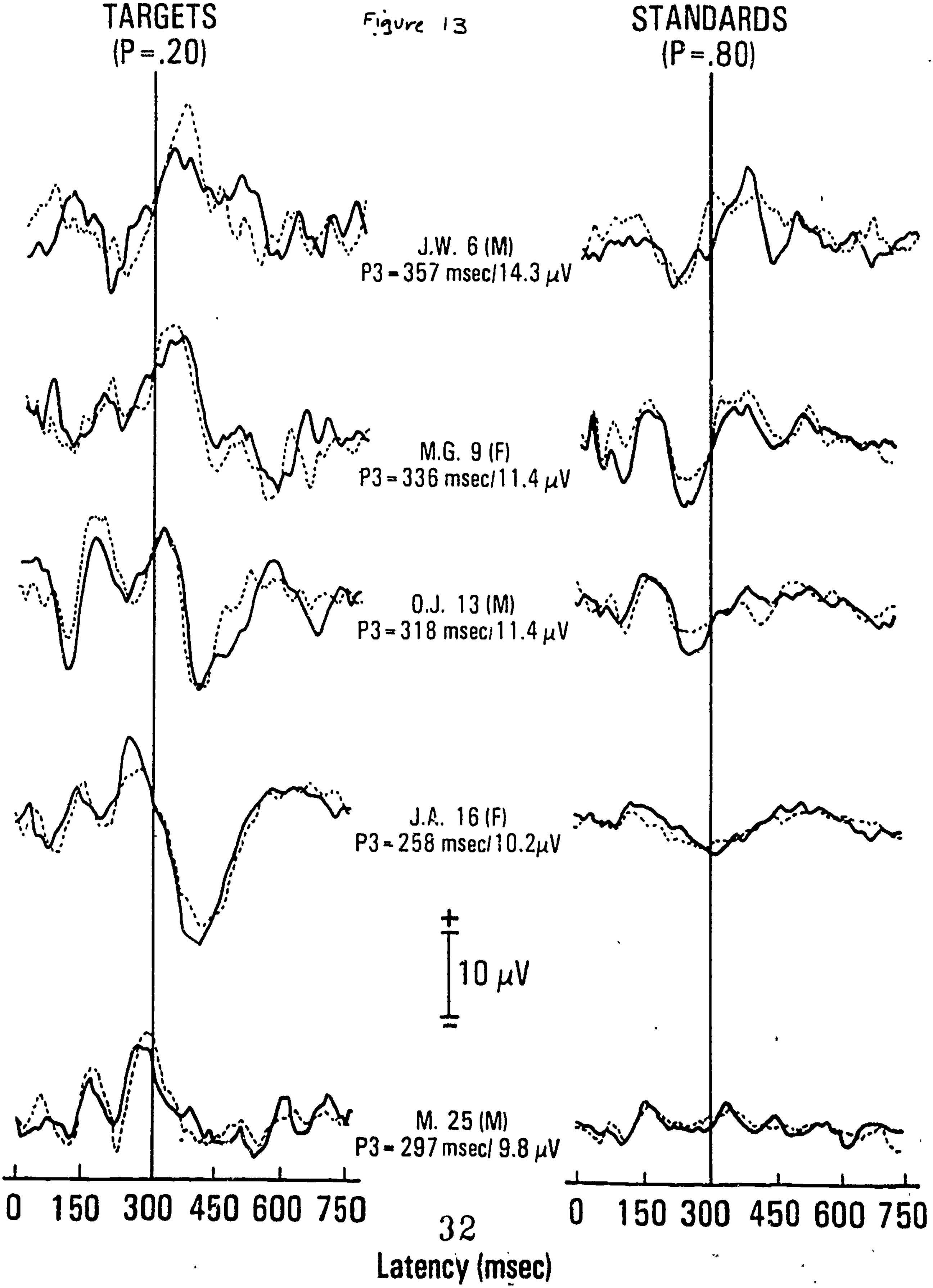

CHILDREN
(n=24)
ADULTS
(n=24)
MEMORY SCORE
17
15
13
11
9
7
Y=3.45+0.69X
r=0.68, p<0.001
4 5 6 7 8 9 10 11 12 13 14 15
AGE (years)
Y=15.2+0.1X
r=-0.13, n.s.
21 23 25 27 29 31 33 35 37 39
AGE (years)
P300 LATENCY (msec)
500
400
300
Y=406.3-6.6X
r=-0.59, p<0.005
5 6 7 8 9 10 11 12 13 14 15 16 17
MEMORY SCORE
Y=337.1-3.2X
r=-0.15, n.s.
5 6 7 8 9 10 11 12 13 14 15 16 17
MEMORY SCORE
P300 LATENCY (msec)
500
400
300
Y=390.4-5.2X
r=-0.48, p<0.025
4 5 6 7 8 9 10 11 12 13 14 15
AGE (years)
Y=245.7+1.6X
r=0.21, n.s.
21 23 25 27 29 31 33 35 37 39
AGE (years)

Figure 13



TARGETS
(P=.20)
STANDARDS
(P=.80)
J.W. 6 (M)
P3 = 357 msec/14.3 μV
M.G. 9 (F)
P3 = 336 msec/11.4 μV
O.J. 13 (M)
P3 = 318 msec/11.4 μV
J.A. 16 (F)
P3 = 258 msec/10.2μV
+
10 μV
M. 25 (M)
P3 = 297 msec/ 9.8 μV
0 150 300 450 600 750
0 150 300 450 600 750
Latency (msec)

Figure 14

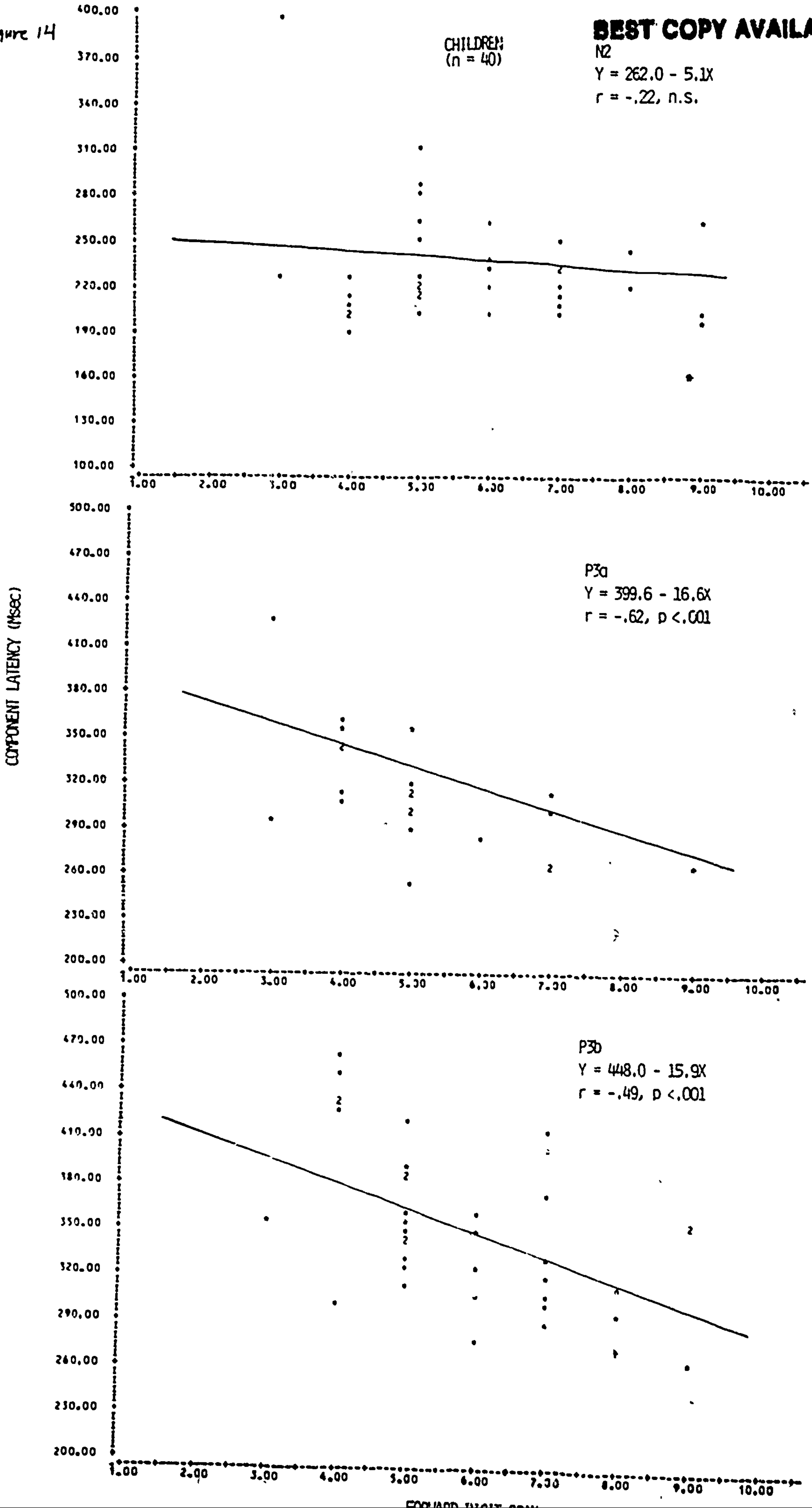
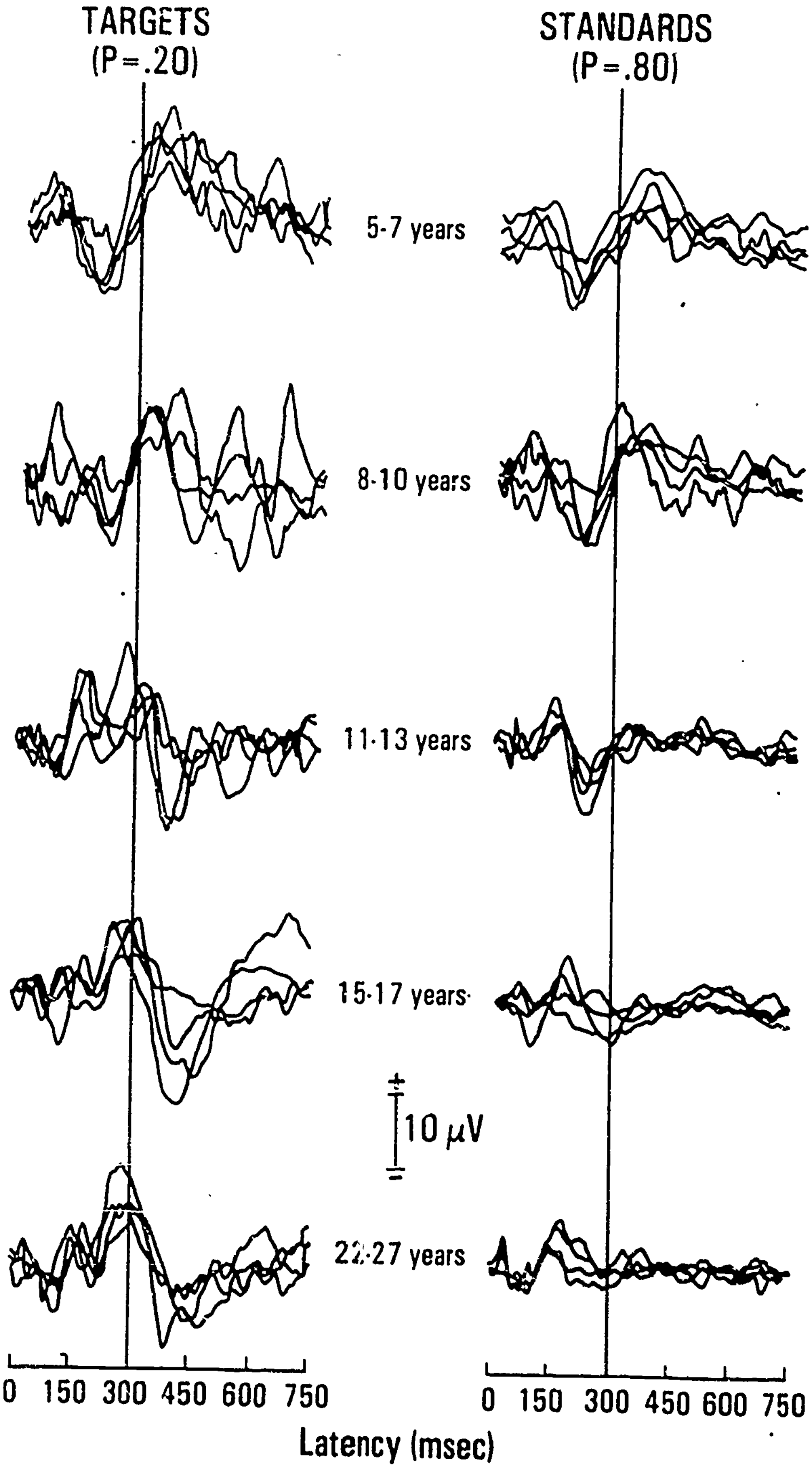

CHILDREN
(n = 40)
N2
Y = 262.0 - 5.1X
r = -.22, n.s.
P3a
Y = 399.6 - 16.6X
r = -.62, p <.001
P3b
Y = 448.0 - 15.9X
r = -.49, p <.001
COMPONENT LATENCY (MSec)
400.00
370.00
340.00
310.00
280.00
250.00
220.00
190.00
160.00
130.00
100.00
500.00
470.00
440.00
410.00
380.00
350.00
320.00
290.00
260.00
230.00
200.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00

Figure 15


TARGETS
(P=.20)
STANDARDS
(P=.80)
5-7 years
8-10 years
11-13 years
15-17 years
22-27 years
10 μV
0 150 300 450 600 750
0 150 300 450 600 750
Latency (msec)